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Weatherproofing Experiment with PL-259 Connections

Water seepage into the PL-259 connector is common, and can significantly degrade the electrical properties of the connection.

The PL-259 is the dominant male coaxial cable connector used for indoor and outdoor coax cable connectivity. Outdoor service is far more demanding due to weather. The seepage of water into connections such as the PL-259 is common as they are not waterproof. This can significantly and quickly degrade the electrical properties of the connection. This experiment deals only with liquid water, not freezing issues, nor the effects of ultra-violet damage or temperature cycling issues. Pity the poor outdoor PL connector.

Most station transmission line systems have inserted components such as power and SWR meters, filters, switches, and of course PL-259 connectors. These items will present a characteristic impedance close to the $Z_0 = 50\ \Omega$ of the transmission line. However, even small variations from the transmission line Z_0 by such components will be seen as an impedance discontinuity to the forward wave propagating down the line. Discontinuities inherently result in a reflection of a portion of the forward power, which is reflected back to the source, and is lost.

Overall, the discontinuity is small and reflected power is minimal, so the PL-259 works well enough, provided the connection is *tight and dry*. "Water in the coax and connectors will manifest itself as loss, and will attenuate the transmitted incident power as well as reflect power due to mismatch. The SWR meter will report a lower SWR due to the attenuated reflected wave indicating better performance than is the actual case".

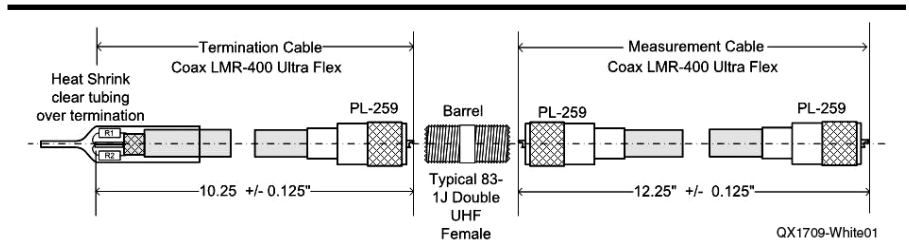


Figure 1 — Test cable construction.

The SWR meter, commonly connected in-line, constantly advises us of the system SWR[1], indicating reflected power in part due to connector impedance discontinuities. Another way to measure impedance discontinuity is by Return Loss (RL). This is the ratio of forward power to reflected power expressed in decibels. Table 1 shows the relationship of SWR to RL in terms of percent reflected power.[2] In this experiment both SWR and RL are measured using the Array Solutions, AIM-4170 Antenna Analyzer over the frequency range 1 to 150 MHz

Weatherproofing Test

The question arises, "what techniques are most effective in protecting the connections?" A controlled experiment is needed to objectively measure the effectiveness of various weatherproofing techniques commonly employed to PL-259 connectors. This would require building a number of identical test cables, each being weatherproofed differently. Certain parameters would be measured under identical and consistently wet conditions. It is unclear how to do this outside in the weather, under widely varying ranges of temperature and moisture. Therefore, an indoor controlled environment, bench test, is needed to make valid comparisons.

This led to the construction of 8 identical test cables, using LMR-400-UF (Ultraflex) coax, each with a unique weatherproofing applied over a central PL-259 connection. Each of the 8 test cables(Figure 1) consists of

Table 1.
SWR, Return Loss, and Reflected Power.

SWR	1.1:1	1.2:1	1.3:1	1.4:1	1.5:1	2:1	3:1	4:1	5:1	10:1
RL, dB	26	21	18	16	14	9.5	6	4.4	3.5	1.7
Reflected Power, %	0.23	0.8	1.7	2.8	4	11	25	36	44	67

2 sub-cables. One sub-cable is terminated at one end with a metal film resistor trimmed to 50 Ω, within 0.1 Ω, and a PL-259 is connected to the other end. This is the *termination cable*. The second sub-cable cable is terminated at both ends with PL-259 connectors. This is the *measurement cable*. The two cables are joined with a female–female SO-239 style barrel, and weatherproofing is applied over the connection. The technique for assembling the PL-259 onto the coax cable is shown in the Appendix.

How to Test for Water

A continuous immersion process was used to accelerate the ingress of water and the rate of degradation of the connections. Measurements would be made in comfort over a few weeks at room temperature. A plastic tub was modified to hold cable joints under water keeping the connections continuously wet and the ends dry (Figure 2).

Weatherproofing Techniques

Five different commonly available waterproofing materials are listed.[3, 4, 5, 6] The eight cables were dressed using either singly, or combined materials according to Table 2. Two of the 8 cable preparations are shown here as examples. Figures 3A and 3B show Cable #1, an untreated connection with no waterproofing applied. Figure 4A and 4B, Cable #4, show the wrapping of the various tape layers. Each tape is overlapped 50%.

Table 2.

List of cables and water proofing techniques.

Cable 1	No weatherproofing applied.
Cable 2	Black Electrical Tape. Scotch® Super 88, a durable tape for the outdoor environment
Cable 3	Black Electrical Tape + a stretchable rubber, self-vulcanizing " Fusion" tape
Cable 4	Black Electrical Tape + Fusion tape + Black Electrical Tape
Cable 5	STUF® a Dielectric Grease which fills voids and displaces water in a connection
Cable 6	STUF® + Black Electrical Tape
Cable 7	Black Electrical Tape + Coax Seal®, a hand-moldable, tacky, black plastic mastic
Cable 8	Generic Heat Shrink tubing with internal "Glue" that seals the connection

Figure 2 — The water bath with seven cables immersed, and one dry reference cable.

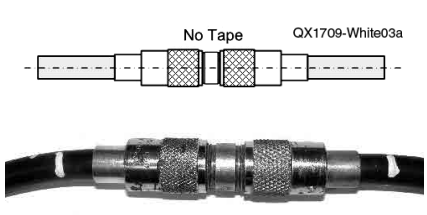


Figure 3 — An untreated connection with no waterproofing applied, (A) drawing and (B) image.

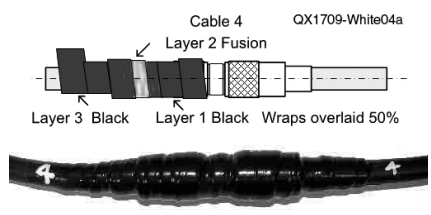


Figure 4 — The wrapping of the various tape layers, (A) drawing and (B) image. Each tape is overlapped 50%.

Test Plan

Each cable was characterized when dry, which established the "Base Line" against planned wet measurements. The dc resistance was measured using a Fluke 73 DVM. The dc termination resistance of all cables was trimmed to 50 Ω ±0.1 Ω. SWR and RL measured using the AIM 4170 Antenna Analyzer. All cables measured the same when dry. The cables were immersed and measured nominally at 1 day, 2 days, 6 days, 12 days and 22 days, to record change in dc resistance, SWR and RL. At the end of 22 days, each cable was stripped of its weather protection and examined for ingress of moisture.

Test Results

After 22 days wet, the change in performance is illustrated in Figure 5, the SWR and RL sweeps of all 8 cables. Half the cables exhibited significant degradation over the 22 wet days. All tapes were removed and all PL-259 connectors and barrels were inspected for water ingress. Deficiencies were noted, particularly with Cables #3, #4 and #6. Cable #1 was not expected to perform at all well, and it didn't.

Erratic dc resistances were noted in some measurements with variations of greater than a few ohms to open-circuit under agitation of the joint. Some tapes lost adhesion and developed loose ends, and were starting to unravel. When a loose connection was noted the connector was not tight to the barrel. Water was observed under all the tapes.

The suspect cables (#3,# 4, and #6) were rebuilt with greater care and attention in the application of the weather proofing tapes, and those with STUF® were re-constructed ensuring that the connector to barrel mechanical connection was tightened to squeeze out surplus grease. The PL-259 shells were gently tightened with slip jaw pliers in all cases. Cable #2 performed beyond expectation. It was rebuilt to confirm the performance. The reworked cables were retested using the same techniques under the same 22 day regimen.

Re-Worked Test Results and Findings

The second batch of tests were much improved as seen in Figure 6. The graph

shows the change in SWR and RL using day 0, dry as reference, to day 22, wet. Cable #1 was not expected to improve and did not. Cable #4 showed little improvement.

After the 22 day sweeps were completed, the weatherproofing materials were carefully removed and inspected as described earlier. The biggest surprise continued to be the ingress of water under *all* tapes. When removing the tapes, a totally unexpected leakage path was revealed as seen in Figure 7A and 7B. The over-lapping of tape as it is wound on the cable, appears to create an unavoidable, continuous, and miniscule void where the overlap steps down off the tape, on to the surface of the cable. This generates a spiral leakage path for moisture to wick along the cable surface up to the PL-259 connector. This wet path was observed when removing the tapes.

Given time, water variously accumulated on the PL-259 and barrel and shell. Once water appears on or around the PL-259 connector, it will likely enter the connection as illustrated in Figure 8. The most significant water ingress point is indicated by the upper arrowed line. A gap between the shell and the barrel of the PL-259 connector, varying by manufacturer, was variously measured from 0.01" to 0.05". This allows water to flow unimpeded all around the outside of, and along the barrel, onto the face of the connection where it can accumulate in the void between the connector faces. Moisture here would account for the significant effects seen on the SWR and RL graphs.

A lesser path exists as indicated by the lower arrowed line, where water wicks in between the outside of the coax jacket and the internal threads of the barrel. The connection is tight, but not waterproof. Water thus flows to the interior of the barrel and

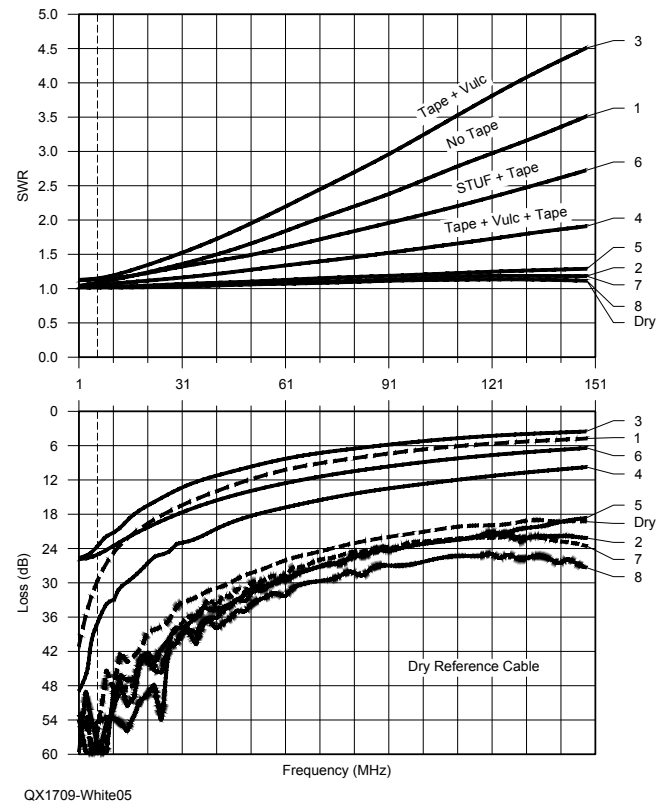


Figure 5 — First construction test results.

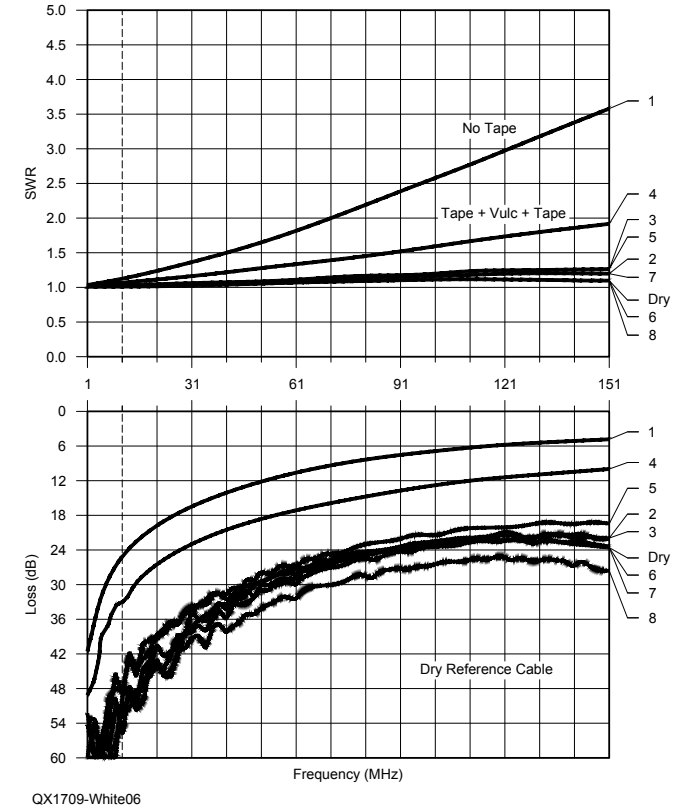
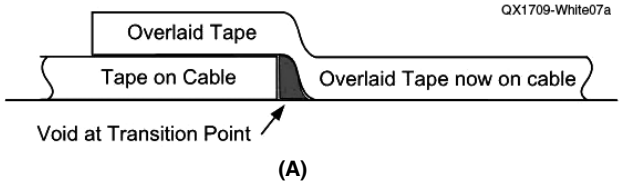


Figure 6 — Second construction test results.



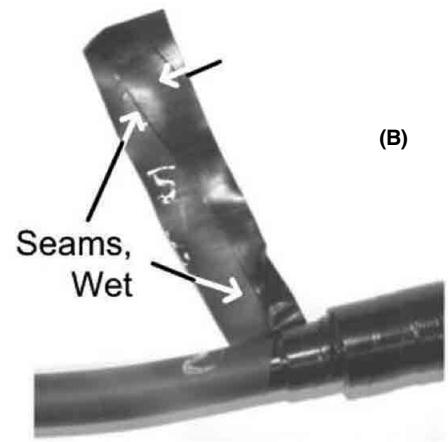


Figure 7 — Overlapping tape water channel follows the void (A), and can be seen (B) as a wet seam.

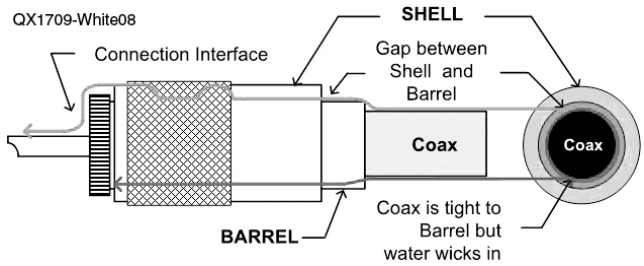


Figure 8 — PL-259 water ingress paths.

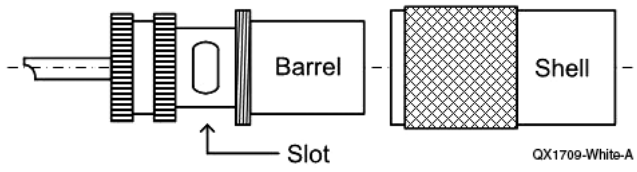


Figure A — PL-259 connector showing the shell, barrel and slot.

enters the chamber at the inside end of the barrel where the coax end has been exposed for soldering. This opens the possibly of water wicking into the coax itself. SWR and RL would further degrade.

The Bottom Line

Over the HF range, all cables came within a 2:1 SWR when assembly techniques were carefully applied. For VHF, degradation becomes more evident and greater attention to weatherproofing is advised. The effectiveness of various materials and methods is as follows.

Keeps Water Out

Heat shrink tubing or Coax Seal® will preserve the integrity of the connection. A heat gun (not flame) is required to perform the heat shrinking operation.

Probably Keeps Water Out

A very effective approach is to apply STUF® to the barrel face as well as the PL-259 face and the threads of the barrel and shell, then tighten. Wrap a layer of black electrical tape over the joint. Then use Coax Seal® to seal the ends of the black tape against leakage and prevent unraveling. This construction was later tested on its own for 21 days immersed. Performance did not change from day 0, dry. Still, moisture was detected under the tape. STUF® saved the day by filling the connection interfaces, displacing water, as none was seen.

Might Not Keep Water Out.

Tapes alone leak, as were seen by the wicking of moisture into the connection. Layering of tapes does not improve matters much as the leak mechanism remains.

Appendix — Installation of the PL-259 to LMR-400 Coax Cable

The integrity of the connection of the PL-259 to the coax is critical to this experiment. The technique for installing connectors is described here.

Requirement 1

Ensure that each PL-259 connector is soldered to the coax braid at all four solder holes, as well as at the center conductor to the center pin to ensure electrical stability.

Requirement 2

Ensure each of the four solder holes and the center pin of the PL-259, are soldered shut to prevent the possibility of water entry here, even though the PL-259 might leak elsewhere.

LMR-400 was used due to the cable construction. It has an aluminum foil on top of the dielectric and underneath the factory-tinned braid. While this provides (nearly) 100% electrical shielding, there is a bonus. The process of soldering the braid to the barrel often involves considerable heat to be applied for some time to induce solder flow between the barrel and braid. Without foil to contain dielectric melt, the dielectric will ooze up through the braid, fouling the solder connection. In many cases the braid is not even tight to the barrel, and little to no heat transfer takes place, and so the connection is either fouled or incomplete, or both. The four small solder holes fill with solder quickly without any confirmation that the braid underneath has actually picked up solder. The solution to these problems is to cut open a slot between any two adjacent holes with a Dremel ® tool equipped with a cut-off disk, see Figure A.

Tin the LMR factory-tinned braid with a little more solder. Screw the connector on to the coax and watch the braid pass by the slot and become fully engaged on the coax cable. Clamp and hold the coax steady in a vise.

Take a hot, tinned soldering iron of considerable thermal mass and place the tip in the slot, heating both the barrel and the tinned braid at the same time. Start feeding solder. Very soon solder will flow on both the braid and the barrel. You can visually verify the connectivity.

While the assembly is hot, go to the two remaining holes, insert the tip of the iron into the hole and feed in solder, which will wick in to the hole almost immediately. Visually inspect the solder joint. The benefits of this procedure are (1) visual verification of the solder joints, and (2) containment of dielectric melt compromising the joint due to the foil.

While hot, the center pin must be wiped clean with a rag down to the original diameter of the center pin, or be filed down when cold, to ensure the connection from the PL-259 to either an SO-239 or female to female barrel is smooth and with no distortions.

John White, VA7JW, earned the Canadian Basic license, VE7AAL in 1959 and upgraded to Advanced in 1960. He attended technical high school in Victoria BC, 1957 through 1960, then enrolled in Victoria University in 1960. One year later, he enrolled in Engineering University of British Columbia (UBC) in Vancouver, and graduated as Electrical Engineer in 1965. He achieved Professional Engineer (P.Eng) status in 1968. His working career includes GTE, Lenkurt Electric, Glenayre, and Norsat. John remained an active HF ham throughout. He belongs to the Victoria Short Wave Club, VE7EZ, North Shore Amateur Radio Club, VE7NSR, and Orca DX and Contest Club, VA7ODX. John has published technical articles in The Canadian Amateur, (TCA), QST and QEX.

Notes

[1]View forward and reflected waves resulting in a standing wave at, **https://en.wikipedia.org/wiki/File:Standing_wave_2.gif**.

[2]For the relationship between SWR, RL, Power, Losses see, **radio.feld.cvut.cz/personal/matejka/download/VSWR%20table.pdf table**.

[3]Scotch Super 88® Electrical Tape, **solutions.3mcanada.ca/wps/portal/3M/en_CA/CA-Electrical/Home/Solutions/Mining/?PC_Z7_RJH9U5230GG7802DQ1VSFM1ON4000000_nid=GS6VLXWVB0gsS8HLFF93PWglKMCP5CD39Xbl**.

[4]Self-Vulcanizing Fusion Tape #122, **www.plymouthrubber.com/wp-content/uploads/2015/02/catalogous_plymouth.pdf**.

[5]See STUF®, **www.crossdevices.com/**.

[6]See PacCoax Seal®, **coaxseal.com**.